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Modernization of the VSVEM-1140 electro-mechatronic system for testing the asynchronous motors

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Abstract:

The article is devoted to the description of practical experience in testing the alternating current electric machines. The results of combining the capabilities of digital systems for collecting and processing information with a powerful electromechanical system are presented. It is the combination of two systems of different purposes that enables creating the state-of-the art diagnostic installations combined into one electro-mechatronic system. Practical results of electric machine tests contain clear explanations of fundamental principles and provide a comprehensive assessment of the condition of electric machines. They use methods of direct charging the electric machines with the possibility of recuperation of electric energy during tests. Thermal state of electrical machine nodes is monitored using the thermal forecasting technologies. Both the methods for various types of tests and means for their implementation are described in detail. This article is intended for engineers involved in designing, manufacturing and testing the electric machines.

Keywords: testing and charging stations, high-voltage alternating current electric machines, energy recovery in braking modes, electro-mechatronic system, thermal diagnostics of electric machines

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1. Introduction

According to regulatory documents, every manufactured electric machine must undergo control tests, the main one - a heating test on a special stand, where its load is assumed to be in the nominal mode.

Different methods are permissible for charging the asynchronous motors when testing them regarding warming up; the simplest of which are various brakes (pad, tape, etc.), as well as load by a generator operating on a rheostat [1-3]. When using these methods, the energy spent during the tests is irretrievably lost.

There are the warming-up test schemes in which most of the energy used is returned to the grid [4-8]. Naturally, these schemes are better, but the test devices become more complicated and expensive, therefore, in the test schemes of electrical repair companies, such installations are rarely used.

When it became necessary to create a test station to improve the quality of repaired mine electric motors for driving coal harvesters and increase the period of their trouble-free operation, it was proposed to create a new complex test station, on the basis of which it is possible to conduct the entire set of tests defined by standards [8-10].

To increase the efficiency of the test station and save electricity during tests, this station implemented a load mode with a reverse operation scheme using an asynchronous generator controlled by the power grid. In addition to testing electric motors for warming up, loading them in the nominal mode, state-of-the-art electronic devices were developed and manufactured for the test station ion all the necessary stages of testing, which are provided for by current national and international standards, i.e.:

1. TestEM FR "TestFron" - a device for testing the electrical strength of the body insulation of rotating electric machines with a voltage of up to 1140 V relative to the body of the machine and between the windings, and burning of the body insulation with alternating or constant voltage (≈5/=7.5 kV);
2. TestEM Tesel-5 - a device for testing the insulation of bulk windings (5 kV, 6.6 kHz);
3. TestEM Sentor SR3 - a device for testing the insulation of rigid sections (8-16-26 kV, 50 Hz);
4. TestEM AN1 Actron - a device for testing the steel - to determine specific loss of steel;
5. TestEM IR Intor - rotor tester - a device for detecting malfunctions and damage in rotors with short-circuited rods during their manufacture, repair or preventive inspection without limiting their power;
6. TestEM ST Shast - a device for monitoring the insulation of the sheets of active steel;
7. Vibration spectrum analyser 795M107Vi;
8. Thermal imager Flir E8-XT.

The test program, methods and scope of tests, methods and devices for measuring electrical and non-electrical quantities, and methods for determining the nominal parameters of rotating AC electric machines meet the requirements of current national and European standards [9-12].

A set of devices for post-operational tests, together with a stand for loading electric motors and the necessary power and measuring equipment, operating in automatic mode under the control of a microprocessor system, made up, as a result, the first version of the complex electro-mechatronic system VSVEM-1140.

This version of VSVEM-1140 enabled control tests of mine explosion-proof asynchronous three-phase electric motors of type SG7W 490L-4 manufactured by Dombrovsky Plant of Electric Machines Damel (Poland) with power of 220 and 250 kW. When testing these electric motors with a load power of the test machine of 220 kW, about 195 kW of electrical energy was returned to the grid.

Fig. 1 shows a screenshot of the SCADA system screen, which displays the active power of the drive motor (blue colour - average power of about 200 kW) and the motor under test (red colour - average power of about 175 kW). In this case, the efficiency of VSVEM-1140 is approximately 87.5%.

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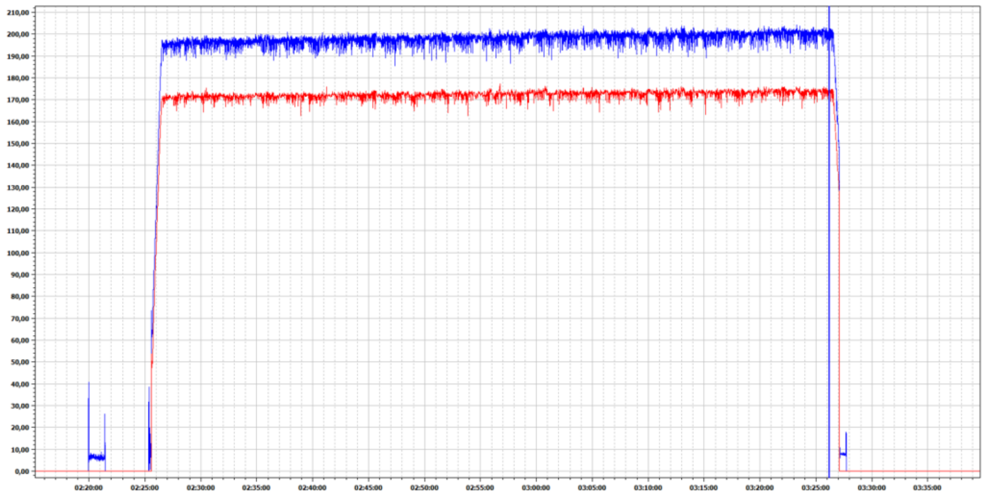

Fig. 1. Active power curves of motors during testing

Prior to the commissioning of VSVEM-1140 in the mines, due to the short life of the electric motors driving the coal harvesters and the need for their frequent replacement, it was not possible to form a sufficient reserve of serviceable repaired engines, which interfered with the rhythmic work and threatened to disrupt the production program. The operation of VSVEM-1140 has shown its high efficiency - the life span of repaired electric motors that have successfully passed thermal tests has increased several times - from several days and weeks to many months.

After analysing the results of the 1.5-year operation of VSVEM-1140 system, it was decided to modernize it to enable testing the mine explosion-proof asynchronous three-phase electric motors with a power of up to 315 kW, voltage of 1140 V and a rotation frequency of 500, 1000 and 1500 rpm. This second version of the electromechatronic system has got the name VSVEM-1140 500-1500.

In the new VSVEM-1140 500-1500 system, all the functions of the first version have been preserved with minor additions, which mainly concern the display of service information (another screen has been added) and the algorithm for calculating the efficiency and torque of the tested electric motor. The main difference of the modernized version is the expansion of the speed range of the motors tested while maintaining the maximum power up to 315 kW. For this purpose, the drive motor 2SGS-355L4, 315 kW, 1140 V, 1500 rpm of the electromechatronic system is rewound to an operating voltage of 380 V at a speed of 1500 rpm to the maximum possible power in the 2SGS-355L4 enclosure, but not lower than 315 kW.

Thus, the modernized electromechatronic system VSVEM-1140 500-1500 is designed for testing the motors with a power of up to 315 kW, a nominal voltage of 1140 V and a different number of poles corresponding to type series 4, 6, 12.

There is a problem of determining the nomenclature of asynchronous motors that can be tested in a long-term load mode by the VSVEM-1140 500-1500 system in the speed range of 500...1500 rpm with a power of up to 315 kW and voltage of 380 V.

The main components of the station are presented in Fig. 2.

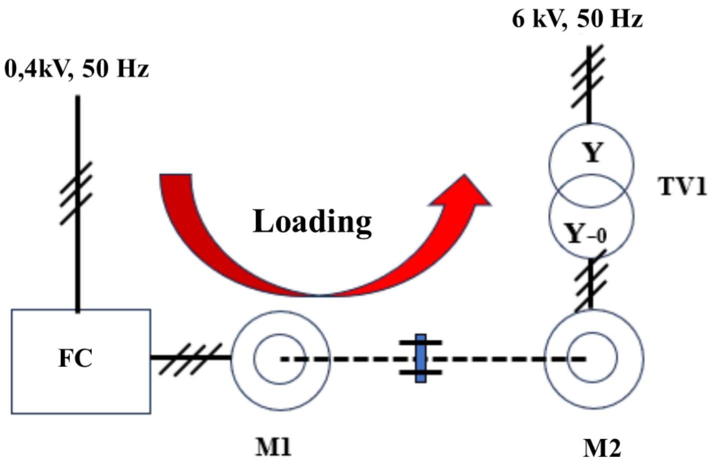

Fig. 2 VSVEM-1140 test station: FC – frequency converter; M1 – loading machine; M2 – tested machine; TV1 - transformer

The load device is represented by the FC frequency converter [13] and the M_1 motor, which brings the test machine into regenerative braking mode. Technical data of the frequency converter are presented in Table 1.

To reduce electricity consumption, the load on the test motors is applied in the generator mode of electricity recovery to the grid. For this, the machine $M_{(2,i)}$ with a supply voltage of 1140 V, different power up to 315 kW and different ideal idle speeds of 500 rpm, 1000 rpm and 1500 rpm are connected via a coupling to the electric motor M_1, and it accelerates to the idle speed $\omega_{(x,i)}$ and then to the ideal idle speed of the corresponding electric machine $M_{(2,i)}$. After that, the machine $M_{(2,i)}$ is connected to the 6kV, 50Hz network through the transformer TV1. For machines of the $M_{(2,i)}$ type, acceleration from the idle speed $\omega_{(x,i)}$ to the ideal idle speed $\omega_{(0,i)}$ occurs already at a frequency of the supply voltage of the motor M1 greater than 50Hz. Next, by increasing the speed of the motor M1, the machine $M_{(2,i)}$ enters the regenerative braking mode and accelerates to the speed $\omega_{(g,i)}$, when the torque of the machine $M_{(2,i)}$ will be equal to the nominal $M_{(n,i)}$ (Fig. 3).

Table 1. Frequency converter FCh5-S0-630/380/50-O70-V00-UHL4

Nominal parameters	Value
Nominal current, A	630
Nominal output voltage, V	380
Nominal output power, kVA	415
Power factor, no less	0,90
Efficiency coefficient, not less, %	95,0
The range of three-phase output voltage change, V	0-380
The range of output voltage frequency change, Hz	0-200

In addition to the standard protection systems of the frequency converter, the control and protection system of the VSVEM-1140 test station additionally includes hardware and software protections, such as protection of the load and test motors by current, power, overheating, temperature, flow and pressure of the coolant, etc.

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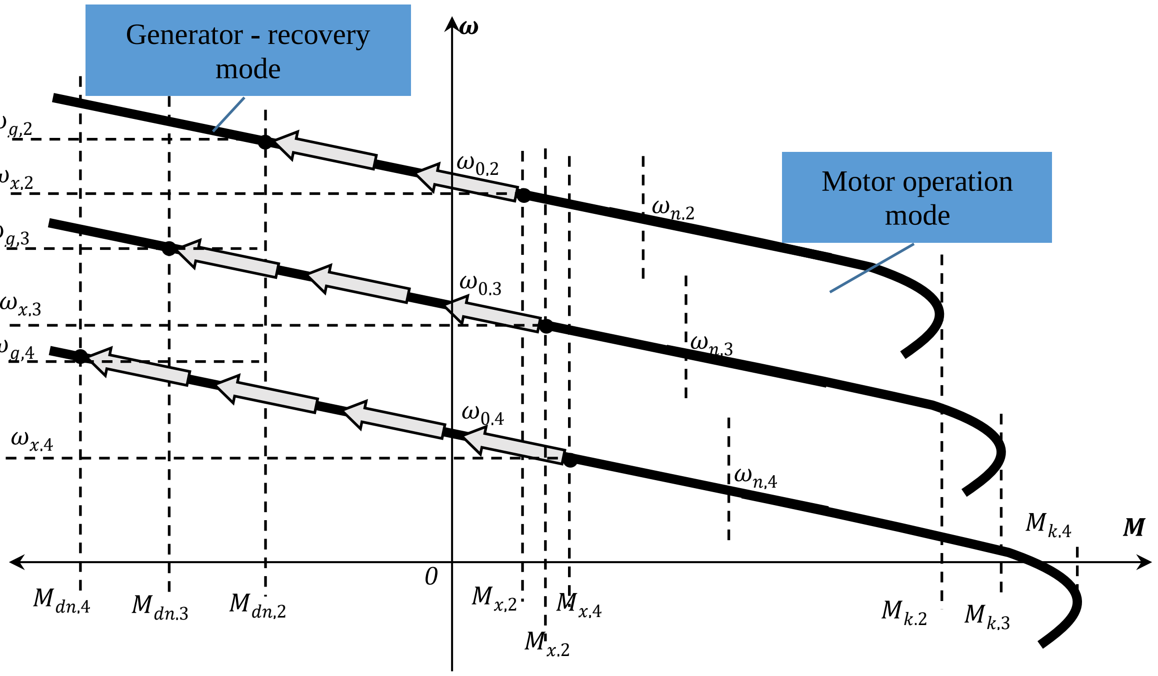

Fig. 3. Mechanical characteristics of tested machines:
i=2 – 1500 rpm; i=3 – 1000 rpm; i=4 – 500 rpm

2. Materials and Methods

The mechanical characteristics of the test machines (Fig. 2) are determined by the simplified Kloss formula in the case when the active resistance of the stator windings of electric machines can be neglected [4, 6, 14]:

$$M_{d,i} = \frac{2M_{k,i}}{S_i/S_{k,i}+S_{k,i}/S_i}, \tag{1}$$

where $M_{(d,i)}$ is the moment on the shaft of the i[th] tested electric machine, Nm; S_i – sliding; $M_{k,i}$ – critical torque, Nm; $S_{(k,i)}$ – critical slip.

$$M_{k,i} = \lambda_i M_{dn,i}\ , \tag{2}$$

where $M_{(dn,i)}$ is the nominal torque on the shaft of the i[th] tested electric machine, Nm; λ_i is its ability to overload.

$$S_i = \left(\frac{\omega_{0,i}-\omega_i}{\omega_{0,i}}\right), \tag{3}$$

where $\omega_{(0,i)}$ is the ideal idling speed, rad/sec.; ω_i is the current angular speed of the i[th] test electric machine.

For the generator load mode, from formula (3) we have the corresponding slip value.

$$S_{g,i} = \left(\frac{\omega_{g,i}-\omega_{0,i}}{\omega_{0,i}}\right). \tag{4}$$

If we consider the working part of the mechanical characteristics of the tested electric machine, where is its nominal working point (corresponding to the points $\omega_{n,2}$, $\omega_{n,3}$, $\omega_{n,4}$ in Fig. 2, that is, when $S_i \ll S_{k,i}$, then equation (1) is further simplified

$$M_{d,i} = \frac{2M_{k,i}S_i}{S_{k,i}}. \tag{5}$$

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From the formula (5) we have the nominal mode of the testing machine

$$S_{k,i} = 2S_{n,i}\left(\frac{M_{k,i}}{M_{dn,i}}\right) = 2\lambda_i S_{n,i}. \quad (6)$$

Considering that in the recovery mode there should be a nominal load torque $M_{(dn,i)}$ on the tested machine during sliding $S_{(g,i)}$, from the formula (5) we get:

$$M_{dn,i} = \frac{2M_{k,i}S_{g,i}}{S_{k,i}}, \quad (7)$$

$$M_{dn,i} = P_{dn,i}/\omega_{n,i}, \quad (8)$$

where $P_{dn,i}$ – nominal power of the tested motor, W.

Substituting formulas (2), (4) and (6) into formula (7), we have

$$\omega_{g,i} = 2\omega_{0,i} - \omega_{n,i}. \quad (9)$$

Realization of the torque $M_{(dn,i)}$ of the tested machine must be secured by the motor M_1. To do this, it will create an active torque $M_{(dn,i)}$ at speed of $\omega_{(g,i)}$, that is, it will realize the following power:

$$P_{d1,i} = M_{dn,i}\omega_{g,i}. \quad (10)$$

To ensure this power, the motor M_1 receives energy from the FC frequency converter with an efficiency of η_1, i.e.

$$P_{d1,i} = \sqrt{3}V_1 I_{1,i} cos\varphi_1 \eta_1, \quad (11)$$

where V_1, $\cos\varphi_1$, η_1 - linear supply voltage, power factor and efficiency of the motor M_1, respectively; $I_{(1,i)}$ is the linear current of the motor M_1, which corresponds to the loading moment $M_{(d1,i)}$.

Thus, from the formulas (9), (10) and (11), the current of the loading motor M_1 is determined:

$$I_{1,i} = \frac{M_{dn,i}\omega_{g,i}}{\sqrt{3}V_1 cos\varphi_1 \eta_1}, \quad (12)$$

where $\omega_{(g,i)}$ is found according to formula (9), $M_{(dn,i)}$ is according to formula (8), and the parameters $P_{(dn,i)}$, $\omega_{(0,i)}$, $\omega_{(n,i)}$ are from the catalogue data of tested motors; V_1, $\cos\varphi_1$, η_1 - M_1 motor parameters.

The recovery mode current $I_{(g,i)}$ of the tested machine is determined for the power according to formula (10), but taking into account the efficiency factor η_i of this machine in generator mode

$$I_{g,i} = \frac{M_{dn,i}\omega_{g,i}\eta_i}{\sqrt{3}V_{n,i} cos\varphi_i}, \quad (13)$$

where $V_{n,i}$,$\cos\varphi_i$,η_i are respectively the rated voltage, power factor and efficiency of the tested motor M_i.

3. Results

According to the above formulas, calculations were made for the motors of different power and speed. The results are presented in Table 2.

Columns 1...10 of Table 2 present catalogue data of electric motors. As a result of using the suggested method, the load currents $I_{1,i}$ of the motor M_1 in the VSVEM-1140 test station and the possible long-term load current $I_{g,i}$ of the motor being tested were obtained.

Since it is planned to use a motor rewound from 1140 V to 380 V as the drive motor M_1, the assessment of its loading current is important from the point of view of overload due to a significant increase in stator currents. After rewinding, the drive motor must have a nominal current proportionally increased in relation to the decrease in the nominal voltage, i.e. assuming the power, efficiency and power factor are maintained at the previous levels, an increase in the current of the stator windings of the drive motor M_1 to the level of 829 A should be expected. From column 14 of Table 2 we can see that the currents of the driving motor do not exceed 588.4 A.

4. Conclusions

Testing the possibility of maintaining the long-term current load of the motors presented in Table 2, using the VSVEM-1140 electro-mechatronic system with a drive motor after rewinding from a voltage of 1140 V to a voltage of 380 V, showed the following:

- motors with a rated power of up to 315 kW, inclusive, with any speed in the range of 500...1500 rpm can be tested at the VSVEM-1140 station with the rated load for these motors in a long-term mode.
- the ratio between the currents of the motor M_1 and the tested machine M_i varies within 2.1...3.5;
- the range of currents 2.1...2.5 is typical for motors with a speed of 500 rpm, and the range 3.2...3.5 - for motors with a speed of 1000 rpm and 1500 rpm, i.e. an increase in speed of the driving motor causes an increase in its current load and losses;
- acceleration of the tested motor in the recovery mode should be carried out with monitoring the current acceleration of the M_1 motor.

Thus, the VSVEM-1140 500-1500 electro-mechatronic system can be used to expand the range of the motors with power up to 315 kW in the speed range of 500...1500 rpm to test their load power in long-term operation.

Table 2. The results of calculating the load on the M_1 engine when testing engines with a voltage of 1140 V

$P_{dn,i}$ kW	n_0 r/min	$V_{n,i}$ V	$I_{n,i}$ A	$S_{n,i}$ %	η_i	$cos\varphi_i$	$\omega_{n,i}$ rad/s	$\omega_{0,i}$ rad/s	$\omega_{g,i}$ rad/s	$M_{dn,i}$ Nm	$I_{g,i}$ A	$I_{1,i}$ A
1	2	3	4	5	6	7	8	9	10	11	12	13
7,5	1500	1140	5	3.4	0.875	0.86	151.7	157.0	162.3	49.5	4.1	14.7
11			7.2	3.9	0.875	0.87	150.9	157.0	163.1	72.9	6.1	21.8
15			10.1	2.5	0.9	0.84	153.1	157.0	160.9	98.0	8.6	28.9
18,5			12.3	2.6	0.95	0.85	152.9	157.0	161.1	121.0	11.0	35.7
22			14	2.4	0.891	0.83	153.2	157.0	160.8	143.6	12.5	42.3
30			18.7	2.4	0.9	0.85	153.2	157.0	160.8	195.8	16.9	57.6
75			49	1	0.922	0.89	155.4	157.0	158.6	482.5	40.1	140.1
90			58	1	0.925	0.9	155.4	157.0	158.6	579.0	47.8	168.1
45	1000		29	1.5	0.916	0.87	103.1	104.7	106.2	436.5	24.7	84.9
55			36.3	1.5	0.922	0.87	103.1	104.7	106.2	533.5	30.4	103.8
75			48.1	1.5	0.932	0.86	103.1	104.7	106.2	727.5	42.4	141.5
90			56.3	1.8	0.934	0.87	102.8	104.7	106.6	875.6	50.7	170.8
315			189	1	0.954	0.88	103.6	104.7	105.7	3040.0	176.4	588.4
75	1500		49	1.8	0.922	0.85	154.2	157.0	159.8	486.5	42.7	142.4
110			70.5	1.8	0.93	0.85	154.2	157.0	159.8	713.5	63.2	208.8
132			84.4	1.8	0.932	0.85	154.2	157.0	159.8	856.2	76.0	250.5
160			104.7	1.9	0.933	0.83	154.0	157.0	160.0	1038.8	94.6	304.3
200			130.8	1.4	0.934	0.83	154.8	157.0	159.2	1292.0	117.2	376.6
45	500		57.6	2	0.825	0.48	51.3	52.3	53.4	877.4	40.8	85.8
132	1500		88.6	1.7	0.91	0.83	154.3	157.0	159.7	855.3	75.8	250.0
55	500		67.5	2	0.826	0.5	51.3	52.3	53.4	1072.4	47.9	104.8
160	1500		102.6	1	0.93	0.85	155.4	157.0	158.6	1029.4	90.4	298.9
65	500		76.1	2.1	0.838	0.52	51.2	52.3	53.4	1268.7	55.3	124.1
200	1500		126.5	1.1	0.932	0.86	155.3	157.0	158.7	1288.1	112.2	374.3
85	500		85.5	2.8	0.84	0.6	50.9	52.3	53.8	1671.0	63.7	164.6
250	1500		152.9	2.1	0.931	0.89	153.7	157.0	160.3	1626.5	138.1	477.4

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